Finescale Planktonic Vertical Structure: Horizontal Extent and the Controlling Physical Processes

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LONG-TERM GOALS

Our long-term goal is to quantify the interactions between small-scale biological and physical processes within the upper ocean. Our work within the *Layered Organization in the Coastal Ocean* (LOCO) DRI examines specific scientific questions that relate the distribution and variability in sub-1m scale bio-optical properties with coincident vertical and horizontal scales of physical properties.

OBJECTIVES

We have made observations in different regions that have confirmed the presence of persistent, small-scale local maxima in the concentrations of nutrients, phytoplankton, and zooplankton. These persistent features result from complex linkages between physical forcing and gradients in the distribution of biological properties. These observations, along with those made by several other teams of investigators, led to the development of the overall programmatic goals of the LOCO DRI. The goals of my research component within the LOCO DRI are to

- quantify the linkage these physical processes and the steep vertical gradients in biological properties within “thin layers”,
- develop a more detailed understanding of the time scales and horizontal spatial scales over which these features persist, and
- evaluate the relative importance of vertical and horizontal processes in establishing planktonic distribution patterns.

APPROACH

As documented in previous annual reports, the LOCO field experiments in 2005 and 2006 yielded extensive data sets on the centimeter-scale vertical patterns of particulate and dissolved matters in Monterey Bay. Our component obtained all its data from ship-based measurements, complementing those obtained by other investigators at the inshore mooring locations. We focused on the bio/physical linkages in the upper water column by conducting high-resolution vertical profiles of hydrographic,

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14. ABSTRACT
Our long-term goal is to quantify the interactions between small-scale biological and physical processes within the upper ocean. Our work within the Layered Organization in the Coastal Ocean (LOCO) DRI examines specific scientific questions that relate the distribution and variability in sub1m scale bio-optical properties with coincident vertical and horizontal scales of physical properties

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bio-optical, and bio-acoustical properties in conjunction with detailed horizontal mapping of layered properties by other investigators within the LOCO program. We used the multiple instruments on our free-fall profiling system (CTD, ac-9s, fluorometers, acoustic Doppler velocimeter (ADV), acoustic Doppler current profiler (ADCP)) to obtain centimeter-scale resolution of hydrographic and bio-optical properties.

Previous work (Cowles, 2004) established that it was critical to resolve the vertical gradients in the horizontal velocity field on scales comparable to those exhibited by the planktonic layers. We found that conventional ADCP measurements over 4m depth bins cannot resolve the vertical shear that appears to form and maintain layers and the steep vertical gradients they display. Therefore, we used a 600 kHz ADCP mounted 1.5m below the ocean surface on a vertical pole off the port side of the *RV New Horizon* (2005) and the *RV Thompson* (2006). In addition, we mounted a second ADCP on our profiling system, although we used a 1 MHz Nortek Aquadopp in 2006 instead of the 600 MHz system used in 2005. The combined boom-mounted ADCP system and profiler-mounted ADV and ADCP systems have provided us with velocity gradients on vertical scales relevant to the biological structure.

The fieldwork in 2005 and 2006 done on the survey vessel was integrated with the broad science objectives of LOCO. In both 2005 and 2006, LIDAR maps (B. Concannon and J. Prentice) and bio-acoustic maps (K. Benoit-Bird) overlap all of the high-resolution ADCP surveys as well as the vertical profiling work. Continuous cross-isobath glider tracks in 2006 (D. Fratantoni) provided essential time series data on the spatial structure of the northern portion of the Bay while we were obtaining vertical profile data in other portions of the Bay. In addition, the glider tracks functioned to extend the mooring array "line" out into our survey domain. Based on the clear need for additional direct sampling of zooplankton outside the mooring array, numerous vertical profiles of zooplankton abundance and composition were obtained with a pumping system (M. Sutor), while over 100,000 high-resolution optical images of zooplankton were obtained with a new CCD camera system (M. Sutor). These complementary projects enhance the interpretation of our vertical profile and ADCP results.

WORK COMPLETED

We have used this year of no-cost extension to focus on the development of integrated data products and manuscripts. This work includes collaborative efforts with Dr. Benoit-Bird, Dr. Donaghay, and Dr. Fratantoni.

Final quality data from the SLOWDROP system for both field years is available on our project website (http://argon.coas.oregonstate.edu/biooptics/projects.htm).

As reported in the FY 2008 report, our analysis of the cross-isobath differences in water column vertical structure between the depth range of the mooring array (~20m) and slightly deeper regions of the bay has revealed considerable spatial gradients in layer formation and maintenance. Our cross-comparisons with Dr. Donaghay's data are based on our multiple shipboard horizontal sections between the 20m and 45m isobaths during the July 2006 fieldwork. During each cross-shelf section, successive vertical profiles were less than 250m apart. Our analysis supports the observation that inner shelf (<25m) conditions, as measured at the mooring array, were often distinct from those observed beyond the 25-30m isobath.

Over the past year we have concentrated our analysis efforts in the collaboration with Dr. Kelly Benoit-Bird. Her multi-frequency acoustic data, collected coincidently in time and space with our high-resolution profiles, has allowed us to address important ecological questions about the aggregation of consumers on layers, as well as the impacts of those consumers on the patterns of overall plankton patterns (Benoit-Bird, Cowles, Wingard 2009).

RESULTS

Our report for FY08 documented the coherence between the small-scale vertical structure of bio-optical properties and the 1m vertical structure of velocity. During those analyses, we observed that the vertical pattern of thin layer shape was not uniform and often displayed distinct differences between the upper and lower gradients in bio-optical properties (Figure 1).

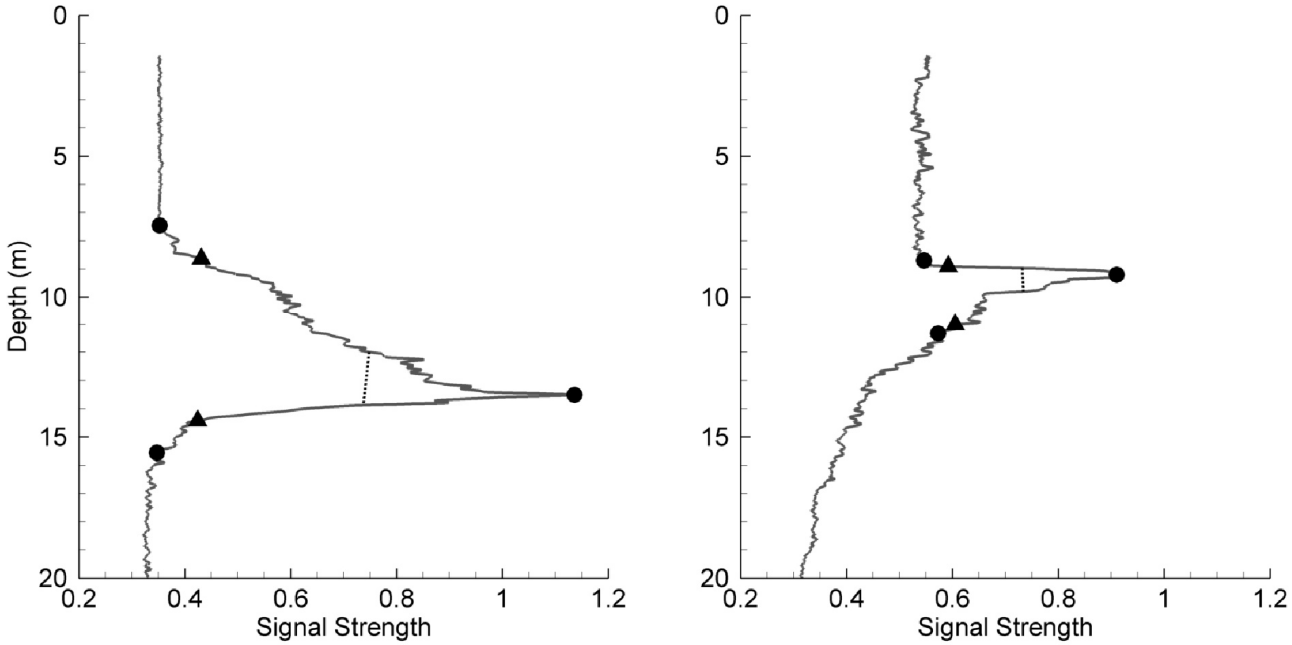

Figure 1. Two sample profiles of thin layers are shown along with the features measured from each profile. The peak of each layer and its intersections with the baseline are indicated by filled circles. The 10% of peak values assuming that that the baseline = 0 and the peak = 1 are shown as solid triangles. Note that because of differences in the baseline above and below the layer on the right, these 10% of peak values are different for the upper and lower gradients. Also shown on each plot are the 50% of maximum peak value for the layer, connected by a dotted line. The difference in depth between these points defines the thickness of the each layer. (from Benoit-Bird et al. 2009)

We compiled all observations of thin layers in Monterey Bay, and analyzed those profiles in relation to the local bioacoustic patterns as well as in relation to the local shear field. We can summarize the nearly 100 layers in 2005 by stating that local Richardson number was nearly always a maximum value at the center of the particulate feature, while the local shear maximum was usually above the particulate maximum (Figure 2). The most interesting aspect of this analysis was the discovery that the vertical gradients in plankton layers were related to the associated abundances in the next higher trophic level (Figure 3).

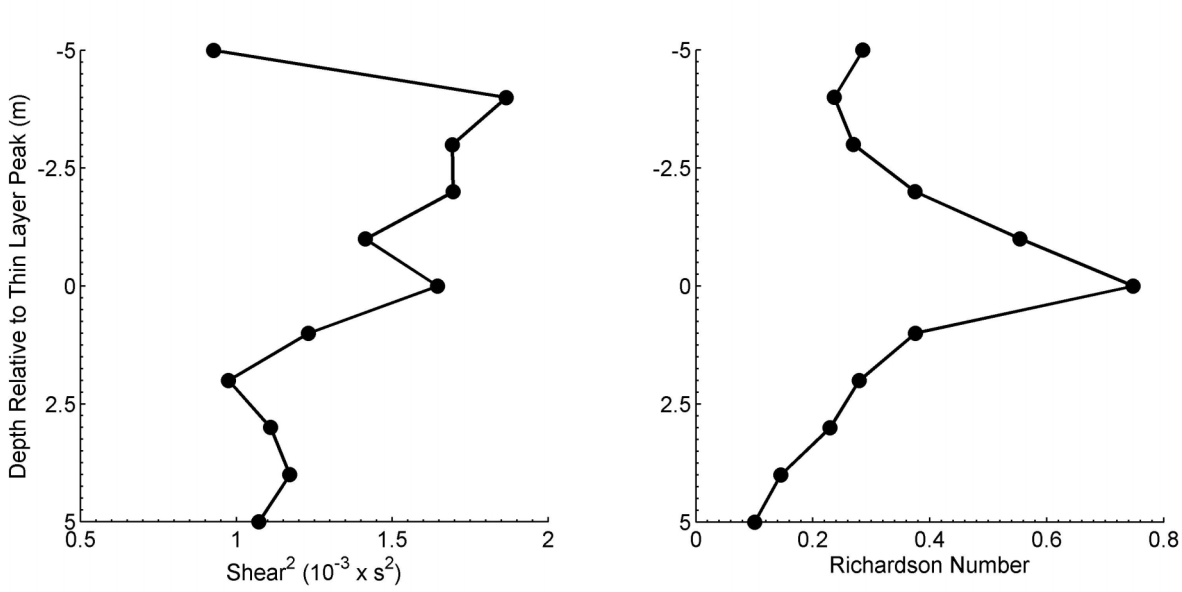

Figure 2. Cumulative plot of the vertical distribution of shear (left panel) and Richardson number (right panel) relative to the center of the peak of all 94 thin layers identified with the SLOWDROP system in the LOCO 2005 field experiment (away from the inshore LOCO mooring array).

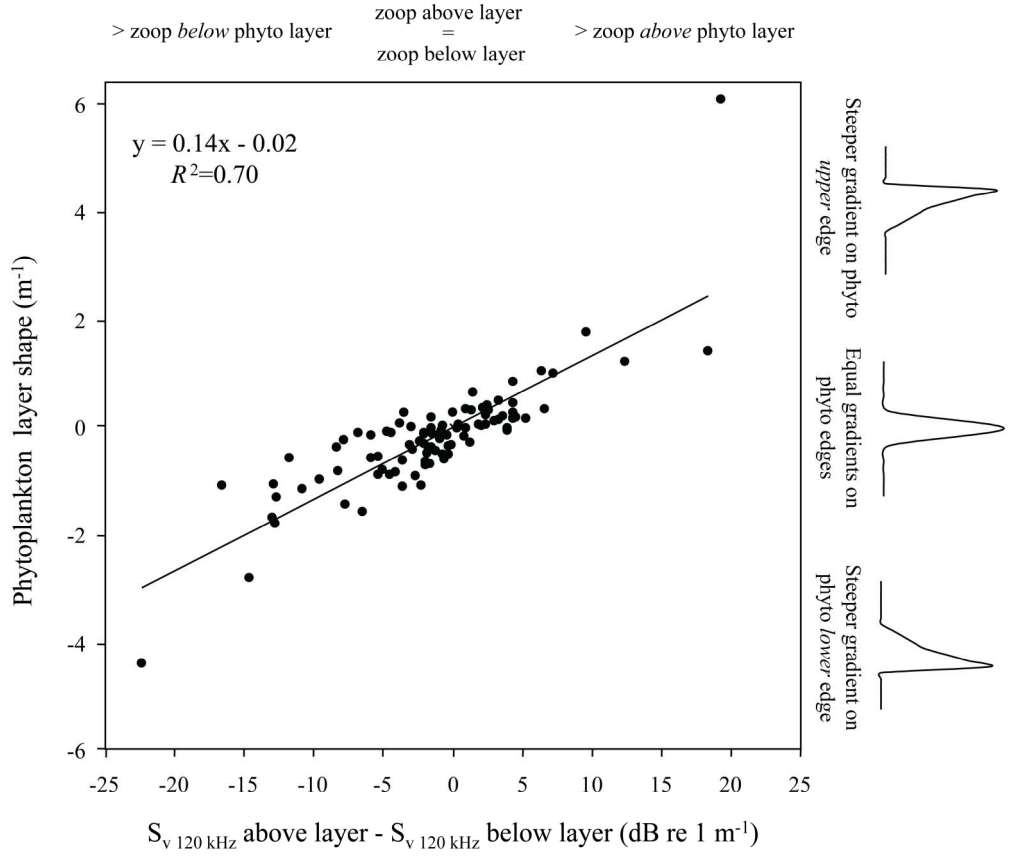

Figure 3. Phytoplankton thin layer "shape" as a function of the local zooplankton gradient. A positive "shape" value means that the top edge of the phytoplankton has a steeper gradient than the lower edge while a negative value, indicates that the lower has the steeper gradient. Volume scattering at 120 kHz was used as a metric of zooplankton abundance. A positive value on the x-axis means that more zooplankton was found in the 2 m above the phytoplankton layer's peak than below it and a negative value, the reverse. Note that the volume scattering data is in dB, a log unit, to permit compression of the scale. Thus, a value of 3 indicates twice as much zooplankton above the layer than below it while a value of 20 represents a 2 order of magnitude difference. (from Benoit-Bird, Cowles, Wingard 2009)

As has been hypothesized for several years, but never documented until this collaborative analysis, local maxima in plankton abundance (thin layers) are sources for aggregations of, and grazing by higher trophic levels.

These observations and analyses illustrate the power of integrated bio-optical and bio-acoustical observations. We would not have been able to derive these interpretations of trophic interactions without coincident measurements with multiple instrument systems.

IMPACT/APPLICATION

Our results from prior studies of planktonic thin layers suggest that the analysis and interpretation of the LOCO field experiments will substantially enhance our understanding of bio/physical interactions

in general, and thin layers in particular. We anticipate that the results will have broad application in ocean ecology.

TRANSITIONS

The results of the LOCO fieldwork will provide new insights into the mechanisms that create that persistent pattern on small-scales, particularly over horizontal scales of many 10s of kilometers. Continued evaluation of these mechanisms will be essential for prediction of the impact of persistent small-scale pattern on the attenuation of optical and acoustic signals in the upper ocean. Observational techniques employing autonomous vehicles and profiling systems may now be applied at various oceanic study sites, thus extending our appreciation of the role that small-scale processes may play in our estimates of water column production.

RELATED PROJECTS

We have active collaborations with the following ONR Principal Investigators:

Dr. Kelly Benoit-Bird, Oregon State University
Dr. Percy Donaghay, University of Rhode Island
Dr. Jan Rines, University of Rhode Island
Dr. Dave Fratantoni, Woods Hole Oceanographic Institution
Dr. Margaret McManus, University of Hawaii
Dr. Jennifer Prentice, NAVAIR
Mr. Brian Concannon, NAVAIR
Dr. Van Holliday, University of Rhode Island
Dr. Malinda Sutor, LSU and WHOI

REFERENCES

Cowles, T.J. 2004. Thin layers of plankton: physical and biological interactions on the small scale. In: *Handbook of Scaling Methods in Aquatic Science*, L. Seuront and P. Strutton, editors, *CRC Press*, Boca Raton, FL., USA, pp. 31-49.

PUBLICATIONS (refereed)

Benoit-Bird, K., T.J. Cowles, and C.E. Wingard. 2009. Edge gradients provide evidence of ecological interactions in planktonic thin layers. *Limnol. Oceanogr.*, 54: 1382–1392

Cowles, T.J. 2004. Thin layers of plankton: physical and biological interactions on the small scale. In: *Handbook of Scaling Methods in Aquatic Science*, L. Seuront and P. Strutton, editors, *CRC Press*, Boca Raton, FL., USA, pp. 31-49.

Alldredge, A.L, Cowles, T.J., MacIntyre, S., Rines, J.E.B., Donaghay, P.L., Greenlaw, C.F., Holliday, D.V., Dekshenieks, M.M., Sullivan, J.M., and Zaneveld, J.R.V. 2002. Occurrence and mechanisms of formation of a dramatic thin layer of marine snow in a shallow Pacific fjord. *Mar. Ecol. Prog. Ser.*, 233: 1-12

Eisner, L.B., Twardowski, M.S., Cowles, T.J, and Perry, M.J. 2003. Relationship between phytoplankton pigment concentration and in situ spectral absorption measurements in East Sound, Orcas Island, Washington. *Limnol. Oceanogr.*, 48: 632-646.

McManus, M. *et al.* 2003. Characteristics, distribution and persistence of thin layers over a 48 hour period. *Mar. Ecol. Prog. Ser.*, 261: 1-19.